PHOTOCONDUCTORS

BY B. R. GAINES

Audio Volume Control with the K42

PART 2

ALTHOUGH a photoconductor is essentially a non-linear device in that its resistance even at constant illumination decreases slightly with increasing applied voltage, at low voltages the departures from non-linearity are so slight that the cell can be used to control small-signal audio-frequencies without introducing distortion.

The basic circuit of a light-operated volume control is shown in Fig. 10. The photoconductor forms the lower leg of a potential divider across the signal voltage. When illuminated it has a resistance of about 100Ω and there is an attenuation of 1,000 times of 60db—when in darkness it has a resistance greater than 10mΩ and the attenuation is negligible. If this arrangement is to be used as a volume control it is required that the photoconductor should change logarithmically when a control is advanced linearly (as in the usual 'log pot'), because the ear responds to stimuli in this way.

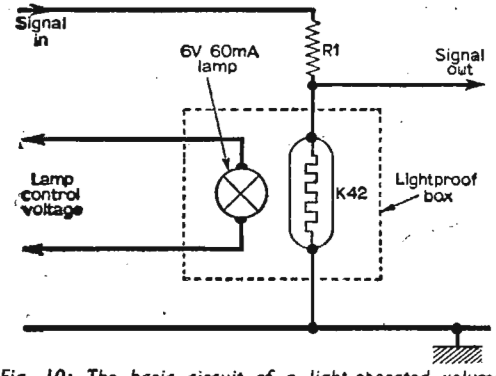

Fig. 10: The basic circuit of a light-operated volume control.

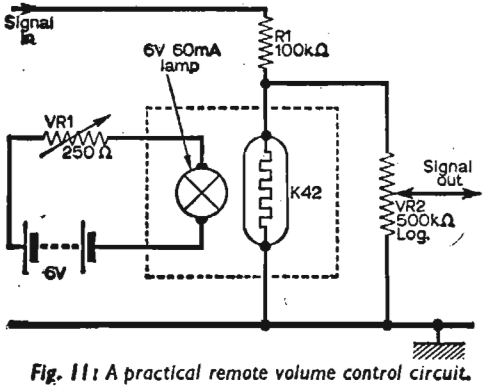

Fig. 11: A practical remote volume control circuit.

A plot of the resistance of a K42 illuminated by a 6·3V 60mA lamp bulb close to its glass window in a light-proof box is shown in Fig. 12, the resistance-scale being of the logarithmic or decibel form. The voltage across the lamp was varied by a resistor VR1 in series with the 6V supply. Curve J shows the variation of photoconductor resistance with lamp voltage, and curve K shows the variation with the lamp series resistance. To get a "log pot" law a control would have to give a straight line on this diagram, and it will be seen that the lamp-voltage curve departs greatly from linearity. The lamp series-resistance curve K however, is much straighter because of the "constant current" characteristic of incandescent lamps, hence a linear series resistor provides the required control.

Remote Volume Control

A practical circuit for a remote volume control is shown in Fig. 11. VR2 is the normal volume control in the amplifier and is set so that with the lamp off the signal is at the maximum required level. VR1 is the remote control: decreasing the resistance of this allows more current to flow

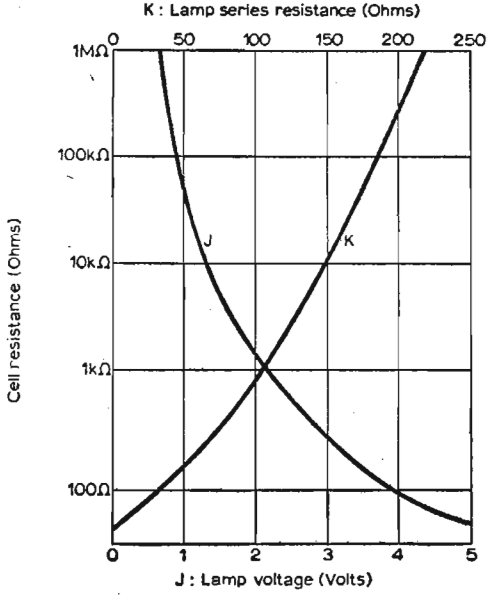

Fig. 12: Resistance graph of the K42 illuminated by an incandescent lamp.

through the lamp making it brighter, thus decreasing the resistance of the photoconductor and hence the signal voltage to the amplifier. If VR2 is not to be used it should be replaced by a 500kΩ fixed resistor to limit the output resistance of the divider when feeding directly into a valve grid. This circuit has the advantage that switching off the lamp leaves the amplifier in its normal operating state, so that power is taken from the battery only when the volume is turned down by remote control.

Even though the cells have a fairly slow response time they are still sufficiently sensitive to 50c/s to pick up the slight ripple on mains-driven bulbs and a d.c. supply to the bulb must be used. The photoconductor must also be protected from ambient lighting so that it responds only to the light of the lamp. They may be mounted close together in a light-proof box or the lamp may be taped to the glass window of the K42 with black p.v.c. tape and the whole unit cocooned in this tape If ambient light leaks into the photocell its resistance will fall and full volume will not be obtained.

Obviously this circuit has a disadvantage over the usual volume control in that it requires a lamp dissipating some 200mW to control audio-voltages of negligible power. This is inefficient but has the great advantage for purposes of remote control that the controlling leads carry no signal voltage and may be as long as required since hum pick-up and brief switching transients on these leads do not get into the audio side. Also the slow response of light bulb and cell provides freedom from potentiometer noise.

Volume Compressor

It is often required to produce a constant output signal from a source which is fluctuating greatly in intensity, e.g. to reduce output variations in a public address system due to differences in the placing or vocal intensity of speakers. There are valve volume compression circuits which achieve this, but they are generally very complicated and difficult to set up. By driving the volume control lamp from the output of the power amplifier it is controlling (Fig. 13) a volume compressor *par excellence* can be constructed such that a thousand to one change of input voltage causes only a three to one change in output voltage, at any power from 60mW upwards.

The reason for this great compression of dynamic range may be seen by reference to curve J of Fig. 12 which shows the variation of photoconductor resistance with lamp voltage. Suppose R1 is 1MΩ and the input signal to the amplifier via the volume control is such that there is 2V output across the lamp, then the photoconductor resistance is 1kΩ and the volume control is attenuating by 1,000.

Now suppose the input signal falls so that the output across the lamp is 1V, then the photoconductor resistance is 100kΩ and the volume control is attenuating by only 10. Thus an input voltage swing of 200 has produced an output voltage swing of only 2!

The circuit of Fig 13 stabilises the output at about 1V which represents 60mW into a 15Ω load or 300mW into a 3Ω load. To make the circuit capable of stabilising any level of output above this figure a variable resistor (VR1) is placed in series with the lamp bulb (Fig. 14). The greater this resistor the greater the output from the amplifier necessary to maintain 1V across the bulb. Thus this control acts as the volume control determining the stabilized output; the normal volume control on the amplifier performs a different function which will be explained in the next paragraph.

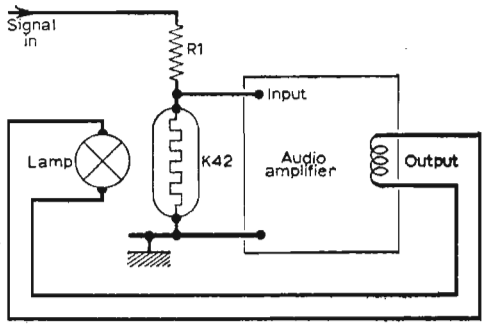

Fig. 13: A volume compressor circuit.

The table below gives the approximate values of VR1 for various maximum output powers into 3Ω and 15Ω loads.

Power	Load	
	3Ω	15Ω
60mW	—	0
300mW	0	60Ω
1W	40Ω	150Ω
3W	100Ω	300Ω
10W	250Ω	600Ω

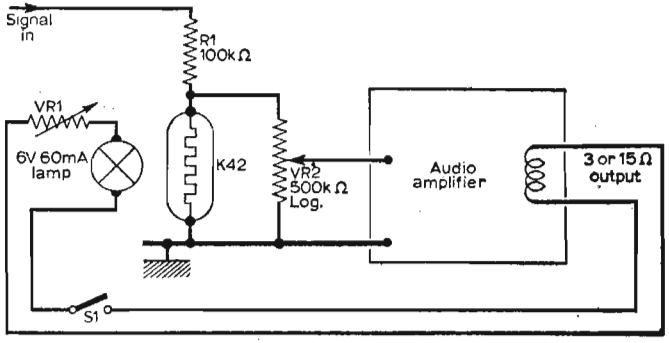

Fig. 14: A volume compressor for variable output levels.

In setting up the final circuit (Fig. 14) the constructor must decide what is the lowest signal which must give full output from the amplifier. The latter must then itself have the sensitivity to give the required output on this signal before all the control circuits are added, since these circuits only attenuate large signals and do not amplify smaller ones. The control VR2 is used to adjust the amplifier sensitivity so that it just gives the required output power on this minimum signal; it controls the range of compression not the output volume.

To set up the circuit the lamp is switched off, the minimum signal fed in and VR2 adjusted to give the required output into the loudspeaker. Then the lamp is switched on, a signal near maximum fed in and VR1 adjusted to give about the same output. Any signal below the minimum will not be compressed and will be amplified normally at maximum sensitivity. Any signal above minimum will come out at the pre-set volume. Since the gain of the system is greatest on low inputs the signal to noise ratio will be increased on these by the volume compression achieved. This trading of noise for compression limits the range of compression which is realisable in practice.

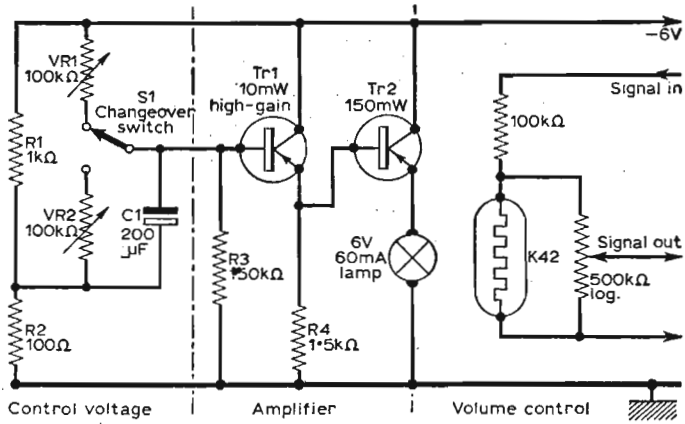

Fig. 15: A circuit for automatic attack/decay control.

Automatic Attack/Decay Control

Automatic volume controls which when switched on "swell up" the sound at a pre-determined rate, and when switched off allow the sound to decay at some pre-determined rate, are used in electronic musical instruments to control the "attack/decay" envelope of the notes: variations of this on a sound of given pitch make all the difference between gentle bowing of a violin and the percussive "ting" of a bell. Also in sound studios similar automatic controls are used to fade sound effects in and out gradually rather than suddenly switching them on.

This type of control is of great help to the amateur tape-recordist trying to mix several inputs with only one pair of hands—instead of having to turn a volume control by hand when he wants to bring in a sound effect, he can just flip a switch and the automatic control will do the rest. As with the volume compressor there are valve circuits to perform this task, but they are complex and generally introduce distortion—here again the K42 circuit scores in simplicity and versatility.

The volume control of Fig. 10 is used again but with the lamp driven by an automatically controlled voltage from a d.c. power amplifier. The output from this amplifier is an almost exponentially rising or decaying voltage which compensates for the non-linearity in the lamp/photoconductor system and produces a constant rate of change of sound in decibels per second — this giving the required audio effect. The rates of rise and fall of this voltage may be pre-set and determine the time taken for the sound to attack and decay.

The circuit of the automatic attack/decay control may be considered in three stages (Fig. 15):

(1) The lamp-driven volume control which is the same as that of Fig. 10 and needs no further explanation.

(2) The two transistor d.c. power amplifier which consists of two emitter followers in cascade. This configuration gives no voltage gain, but matches the very low resistance of the lamp to the high output impedance of the control circuitry.

(3) The control voltage circuit which provides a varying voltage whose rates of rise and fall can be pre-set as required.

The d.c. amplifier circuit is very simple and should present no difficulty in construction provided the correct types of transistors are used. Tr2 provides the power for the lamp and must be capable of dissipating 150mW, any audio transistor with this power rating and medium to high gain is suitable, e.g. NKT223, NKT224, OC81, etc. Tr2 should be in good condition and high-gain, NKT223, NKT224, OC71, etc. — a poor transistor will work but the longest attack/decay times will be unobtainable. When the input to the amplifier is disconnected the output voltage should be less than 0·3V and the lamp should not glow. When the input is connected to the 6V negative rail the lamp should glow brightly.

The control voltage is provided by alternately charging a large capacitor C1 through resistors VR1 and VR2 by means of the changeover switch S1. The resistors are made variable so that the time taken for the sound to swell up or die away may be pre-set. From Fig. 12, curve J, it may be seen that the photoconductor attains its maximum resistance with a lamp voltage of 0·7V and is not affected by voltages below this. Therefore the control voltage must vary above 0·6V and to ensure this C1 is returned not to earth but to a potential divider consisting of R1 and R2 whose junction is about 0·6V negative to earth.

Consider the switch S1 switched to VR2 and C1 completely discharged: the input voltage is then

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0·6V and the lamp is off so that the volume control is up at maximum output. Now S1 is switched to VR1 the "decay" control: C1 slowly charges up through VR1, the voltage across the lamp rises and the resistance of the photoconductor falls so that the volume control output decreases, reaching its minimum when C1 is fully charged; the volume control is now off.

Now S1 is switched back to VR2: C1 slowly discharges through VR2, the lamp voltage falls etc.—the whole cycle being repeated in reverse until the initial state with C1 completely discharged and the volume control at maximum is reached.

With the values of C1, VR1 and VR2 given, the attack and decay times can be varied from several seconds down to practically instantaneous. If longer times are required C1 may be increased to 1,000μF or more.

In this article the writer has described only a few of the possible applications of photoconductive cells. They are a comparatively recent device and many manufacturers in Great Britain and the U.S.A. are working on improved forms and new applications. Their use to replace relays in switching circuits has perhaps the greatest potential at present: a neon lamp or electroluminescent panel can control several photoductors, switching them from virtually open-circuit to virtually short-circuit by means of its light output. The most important improvement to be made in these devices is a great decrease in their response time, at present over one tenth of a second. Cadmium Selenide cells can bring this down to one hundredth of a second and other compounds may bring it much lower. Other photosensitive devices of entirely different principles are also becoming available and the ultimate value of the photoconductor cannot yet be judged, but it is safe to say that it will be with us for many years, assuming greater importance as improved forms become available.

Acknowledgement is made to Ericcson Telephones Ltd. for permission to use their published data on the K42.

The K42 is available from Service Trading Co. at 8s. 6d. It is *not* available direct from the manufacturers in quantities less than 500. ■

PRACTICAL WIRELESS

JANUARY 1965

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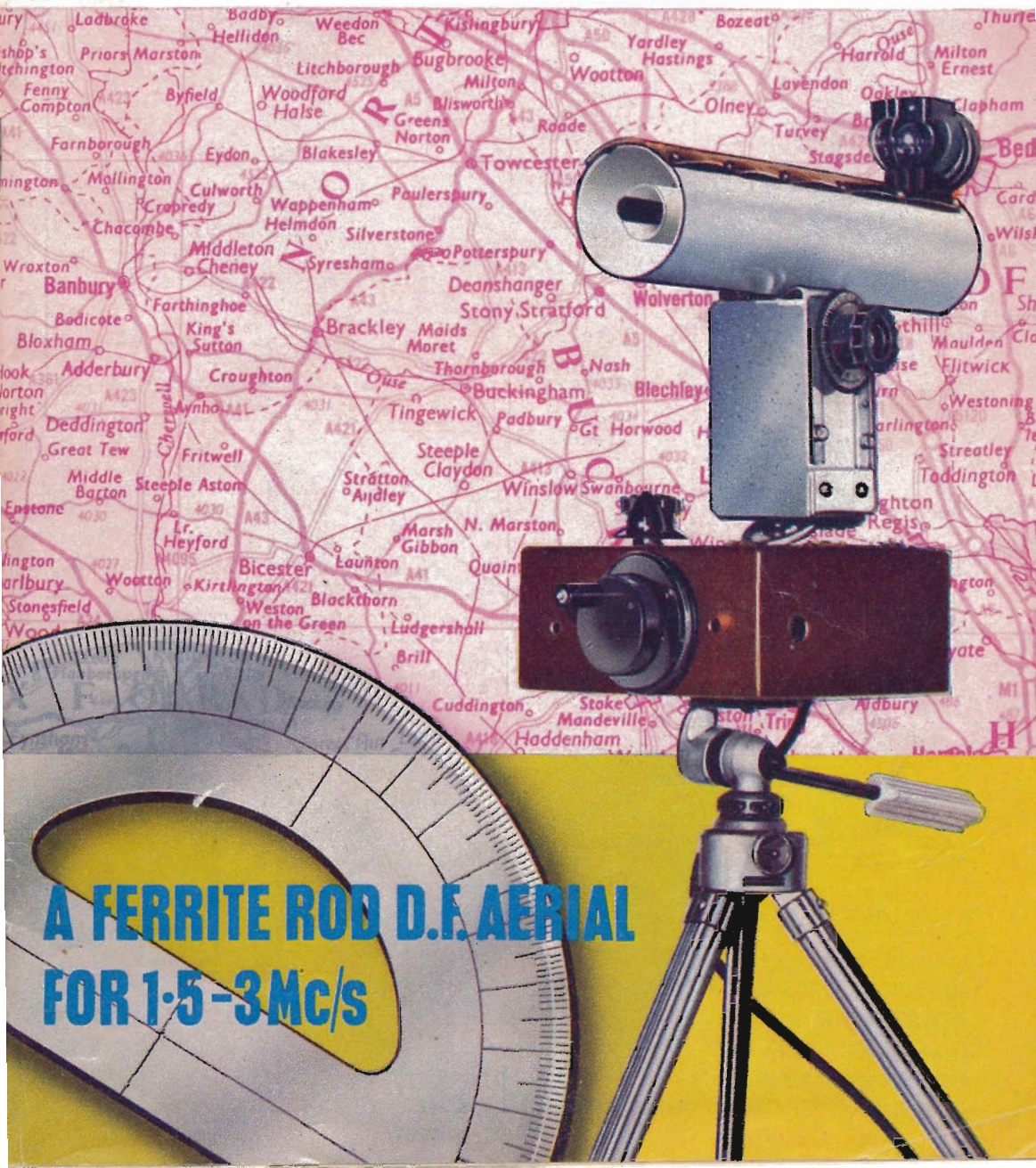

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